

Accelerating Mobility Electrification Beyond Cars with Modular & High Power SiC Traction Inverters

Freight transportation, off-road and industrial vehicles, marine applications and aviation contribute more than 55% [1] of the total greenhouse gas emissions from internal combustion engines.

Electrifying these powertrains could make a large difference in the fight against climate change. However, the large quantity of units in action worldwide is associated with a wide diversity of types and platforms.

By Pierre Delatte, CTO, CISSOID

To develop new electric drives quickly, engineers need all the help they can get. The differences are more than simply physical, in terms of size, shape, and weight constraints. The functional and electrical safety requirements, and environmental conditions, are highly dependent on applications and geographical markets. On the other hand, the competitive situation between all manufacturers demands a fast time to market.

For performance and reliability, silicon carbide (SiC) is the power semiconductor technology of choice. While range-anxiety is one issue that has moved the passenger car market away from silicon and towards more energy-efficient SiC, vehicles such as buses operate on known routes and off-road vehicles cover relatively short distances. For these applications, SiC's high-voltage capability permits faster charging for shorter turnaround times, and its ability to operate at high temperature helps maximise reliability. Moreover, modules require fewer SiC devices to share the duty, and SiC MOSFETs can be smaller in relation to breakdown voltage than their silicon counterparts. Hence, savings in module size are also possible.

However, SiC power devices are not a direct drop-in replacement for silicon MOSFETs or IGBTs. Arranging proper control of the gate to ensure fast and smooth switching transitions at high frequency is not straightforward. There are further challenges including integrating hardware components, especially the inverter and the intelligent power module, and setting up and calibrating the motor-control software.



Figure 1: CISSOID's high-voltage SiC inverter reference design.

Accelerated Development

To help overcome the development challenges and accelerate time to market for robust and reliable SiC power modules (Figure 1), CISSOID has produced a SiC traction-inverter platform and reference design. Drive makers can use this to build systems capable of operating from battery voltages up to 850V. The hardware is modular and scalable to produce designs of various power ratings.

The reference design solves aspects of the inverter that are notoriously difficult and time-consuming to get right. The core components include a 3-phase 1200V intelligent power module (IPM), already integrated with a gate driver optimised for SiC applications and designed to withstand elevated temperatures (Figure 2). The driver provides peak gate currents in excess of 10A and can operate in ambient temperatures up to 125°C.

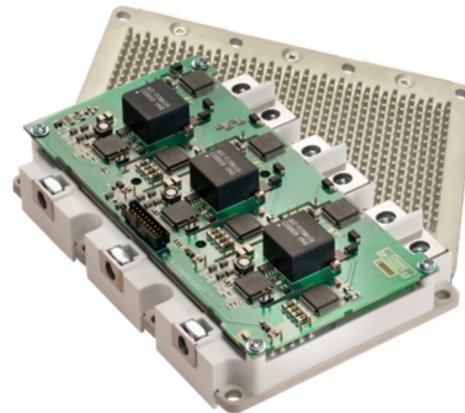


Figure 2: The Intelligent Power Module (IPM) comprises SiC power stage with pin-fin cooling and top-mounted gate driver [2].

Because the SiC gate driver is already integrated with the power module, users can start their projects with a solution that is already validated and optimised for fast switching speed and low losses, immune to high di/dt and dV/dt effects, and that contains robust protections for the power stages. As a result, the number of iterations required to fine-tune module performance and ensure proper thermal management is significantly reduced. Additional hardware in the reference design includes DC-current and phase-current sensors, EMI filtering, a compact liquid cooler and high-density DC-link capacitor. The DC-link capacitors are specifically developed for the inverter platform and cover a broad range of voltage and current options.

Software Control and Calibration

To complete the reference design, there is also an e-motor control board, with an application specific processor and software, both pre-certified to the ISO 26262 standard, ASIL level D for functional safety. The motor control software allows a wide range of adjustments without compromising the functional-safety certification, giving flexibility to optimize the motor behaviour as required in the end use case. The users can run their own custom application software on top of this.

The control board is designed around the Silicon Mobility OLEA® T222 field-programmable control unit (FPCU). This approach allows the reference design to combine the software-based flexibility of a conventional processor with hardware acceleration to ensure real-time performance up to the highest desired motor speed. By including the control board, the reference design also helps users to avoid the usual mechanical and electrical integration challenges when bringing the control board and Intelligent Power Module together.

The OLEA® APP INVERTER is a flexible and fully customisable control software (Figure 3), that matches any electric powertrain configuration and power range thanks to a set a configuration and calibration parameters that can be modified either offline or in real-time. The software also comes with a debugging and calibration framework including a graphic interface.

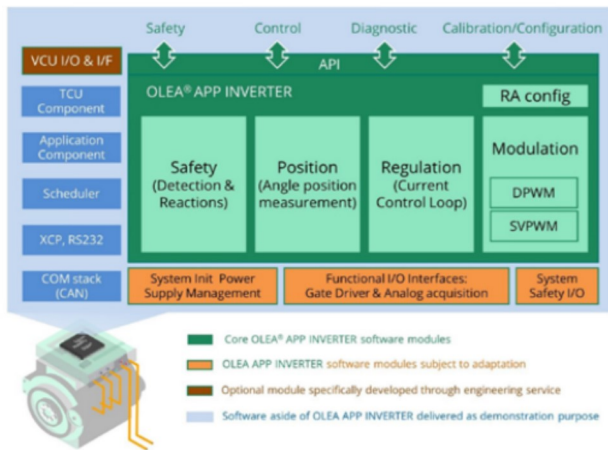


Figure 3: The OLEA® APP INVERTER control software provides multiple features to regulate and optimise motor operation.

Using OLEA® COMPOSER, developers can shorten the time required to optimise the motor control software (see sidebar for more information on the four-step process to accomplish this).

SiC Inverter Performance

After the parameters are set up, the motor can be tested and the efficiency of the inverter-motor combination can be mapped. Figures 4a and 4b compare the performance of the SiC-based inverter with a silicon-IGBT inverter tested under similar real-world conditions.

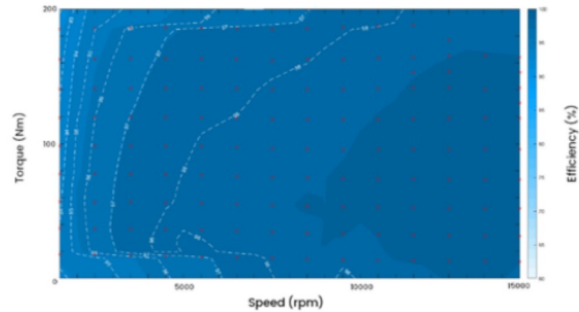


Figure 4a: SiC inverter performance up to 260kW @ 13500rpm, showing efficiency across speed and torque range.

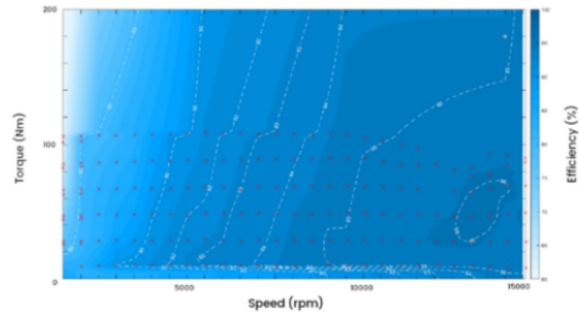


Figure 4b: The silicon-based inverter up to 120kW @ 11500rpm, has impaired torque capability (see cross-points) under comparable conditions.

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Setting up and Calibrating the Drive

The OLEA® COMPOSER tools suite helps the user get the motor spinning according to the customer's specifications. It assists in performing calibration of parameters such as voltage, power rating, speed, and torque to reach an optimal working range. Once this is complete, the inverter-motor efficiency can be mapped.

Setup and calibration are completed in four steps:

Step 1: Software parameters configuration

- Configuration of the OLEA® APP INVERTER software according to the e-motor parameters.

Step 2: Inverter hardware setup

- Setup of e-Motor including components such as resolver and temperature sensors. Connection of EV electronic control unit (ECU) and bench (e.g. CAN, safety) interfaces, power and cooling interfaces.
- Check inverter safety interfaces with the test bench.

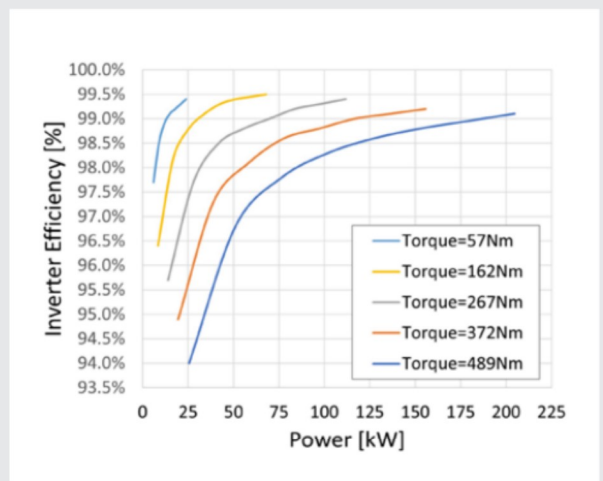
Step 3: Motor-control system calibration

- Open loop mode: calibration of current and voltage sensor signal conditioning chains by the OLEA® T222 FPCU.
- Partial open-loop mode: position sensor offset calibration, whether using resolvers or inductive sensors.
- Current closed-loop mode: internal PI controller tuning of ID and IQ vectors for field-oriented control (FOC).
- Torque control mode: fine-tuning of torque control loop for precision and dynamic response.
- Speed closed-loop mode: speed regulator calibration.

Step 4: Advanced System Optimisation

- Scaling of switching frequency: adjustment of the switching frequency depending on speed and phase currents.
- Dead time compensation: adjustment of the deadtime compensation algorithm to minimise the phase-current harmonics.
- Flux Weakening: ID/IQ setpoints optimisation for an efficient operation in the maximum torque per voltage (MTPV) region.
- SVPWM/DPWM: definition of the threshold between space vector pulse-width modulation (SVPWM) and discontinuous pulse-width modulation (DPWM), offering higher efficiency at high speed.

Using this approach allows tuning of the reference design to achieve efficiency greater than 99%, operating on a 700V bus, up to 4000rpm, as shown below:



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These performance plots show how the greater efficiency of the SiC-based drive ensures a superior user experience. With increasing speed and load demand, the motor torque when operating from the IGBT-based drive, becomes significantly reduced owing to its lower efficiency; the self-heating associated with the energy losses in the device cannot be dissipated without greatly increased cooling. In contrast, the highly efficient SiC-based drive can deliver closer to the maximum torque over a much wider speed and load range.

Conclusion

The bus, truck and agricultural vehicles sectors present a good opportunity for electrification and for reducing the emissions burden on the environment. Silicon carbide power technology can help maximise both reliability and vehicle duty cycle, as well as delivering superior efficiency compared to silicon IGBTs or MOSFETs. The complexities of designing with SiC, and the imperative to ensure a fast time to market, demand a flexible development platform to help designers satisfy the targets for various vehicle categories and types. A complete reference design that offers solutions to the main challenges when designing with SiC, while also allowing flexibility and scalability to address different power ratings and battery voltages to handle small to large vehicles, effectively minimises design risks and helps accelerate time to market.

References

- [1] Source: NESTE: Towards sustainable mobility / April 2023: <https://journeytozerostories.neste.com/transportation/towards-sustainable-mobility#885e75ed>
- [2] CISSOID SiC Intelligent Power Modules: <https://www.cissoid.com/sic-power-modules/>
<https://www.cissoid.com/tools/reference-designs>

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